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research trends

CORNELL AERONAUTICAL LABORATORY, INC., *of Cornell University*
BUFFALO 21, NEW YORK

FIG. 1 — CAL's modified T-33.

Dry-Run in the "X-15"

T-33 Simulates Control Characteristics of Hypersonic Airplane

by WALDEMAR O. BREUHAUS

Also in this issue: "coated abrasives research", page 5

BEFORE a pilot enters the cockpit of the X-15 airplane to fly through the fringes of space at hypersonic speeds, it is highly desirable that he have some knowledge of the handling characteristics of the airplane.

One way to acquaint him with the X-15 is to simulate its handling qualities by means of Cornell Aeronautical Laboratory's variable stability T-33.*

Although the Laboratory's variable stability airplane[1], [2] is used to determine the effects of various stability and control characteristics on the flying qualities of many actual or theoretical airplanes, it is also possible to simulate the flight characteristics of a specific airplane. The most recent work of this nature was done for the U.S. Air Force and involved the simulation of the flight characteristics of the X-15.

An airplane such as the X-15 can be simulated in two ways. The simulated characteristics can be held fixed with respect to time, and the pilot can devote as much attention to the investigation of these characteristics as he considers necessary and desirable. Also,

*Developed by CAL for the U.S. Air Force.

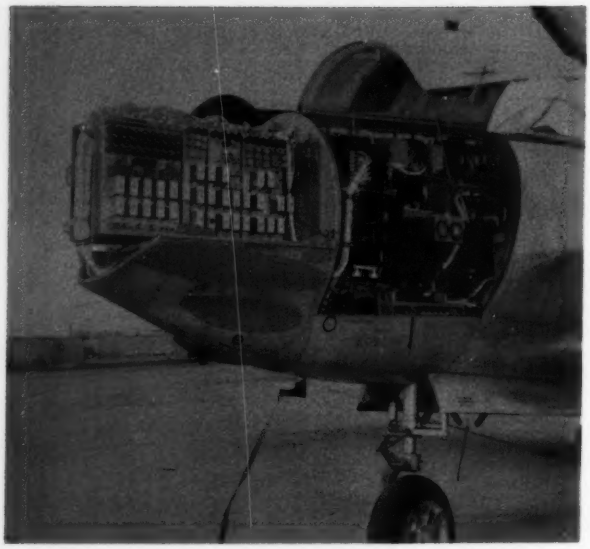

FIG. 2 — **Left-hand side of nose compartment of T-33 showing equipment.**

the simulated characteristics may be made to vary with time in the same way the characteristics of the actual airplane are expected to vary. In the latter case the pilot can experience the progression of events.

Side Controller Used

The pilot conducting the evaluation occupies the front cockpit of the T-33. He can control the airplane by use of standard cockpit controllers (conventional center stick and rudder pedals) or by either a two-axis side controller and rudder pedals or by a three-axis side controller. During the simulation of the X-15, a two-axis side controller was used for much of the work, and this side controller essentially duplicated that of the X-15. The evaluation pilot's controllers are not mechanically connected to the control surfaces, and they do not move in response to that part of control surface motion due to angle of attack, pitching velocity, or other aircraft response. The pilot, therefore, is not distracted by what, to him, appear to be extraneous control surface movements but which actually are movements required to change the stability of the airplane.

The safety pilot, located in the rear cockpit of the airplane, is actually the pilot in command. His normal stick and rudder pedal controls remain mechanically attached to their respective control surfaces at all times. He is able to disengage immediately the special control surface servos, and can assume control of the normal airplane. He also is responsible for setting the gains of the variable stability equipment and for engaging the control system.

It is possible to simulate a wide range of stability and control characteristics with the variable stability T-33. These characteristics, however, will not vary with time, but will yield "frozen configurations". In order to perform simulations of such maneuvers as the re-entry of the X-15, it is necessary to install additional equipment in the airplane so that the gains of the various channels of the automatic control system will be varied properly as a function of time.

Time-Varying Characteristics Introduced

In principle, the safety pilot could modify the stability and control characteristics of the airplane as a specified function of time by proper (and generally continuous) adjustment of the various system gain-control knobs located in his cockpit. This is not feasible, however, in practice. Required gain changes are achieved by an electro-mechanical programming unit. The programmer consists of a governed electric motor driving a number of function generators at a rate which can be adjusted by the choice of gearing between the motor and the function generator drives. A sweep through the cycle during the simulation of the X-15 re-entry required 90 seconds.

The programmer contains 22 separate and independent function generators (Figure 4). Each of these generators can be used to vary the gain of any variable stability loop, to add an incremental deflection of control surface as a function of time, or to act as an input to one of the display instruments on the evaluation pilot's instrument panel.

Each function is wired on a separate resistance board, and is approximated by 27 straight line segments. Different functions can be obtained simply by substituting boards in this compartment. These changes cannot be made in flight, however.

By means of these resistance boards it is possible to simulate re-entry characteristics for various configurations of the vehicle being simulated. During simulation of the X-15 re-entry, for example, it was possible to provide, on different flights of the T-33, the characteristics which would exist with and without the X-15 stability augmentation system (dampers) in operation.

Like the basic variable stability system, the programmer is operated by the safety pilot. In addition to being able to start, stop, and reset the programmer, the safety pilot is provided with a display to inform him of the position of the programmer in its cycle. The programmer can be stopped at any point in its cycle so that the characteristics being simulated at that point can be examined as a "frozen configuration".

Re-entry Maneuver Explained

Re-entry of the X-15 into the atmosphere is accompanied by a wide variation of control characteristics in a short period of time. The re-entry maneuver is preceded by a period during which the aerodynamic forces are very small, attitude control is achieved by means of reaction jets, and the airplane follows an essentially zero-g trajectory.

As the X-15 begins to re-enter the atmosphere, the periods of both its lateral and longitudinal motions are quite long and the damping of the motions is light. Response to control inputs is sluggish, and control authority is limited. The X-15 has a high rate of descent, so atmospheric density increases rapidly with time. Dynamic pressure and aerodynamic forces also increase rapidly. The lift force, and hence the normal

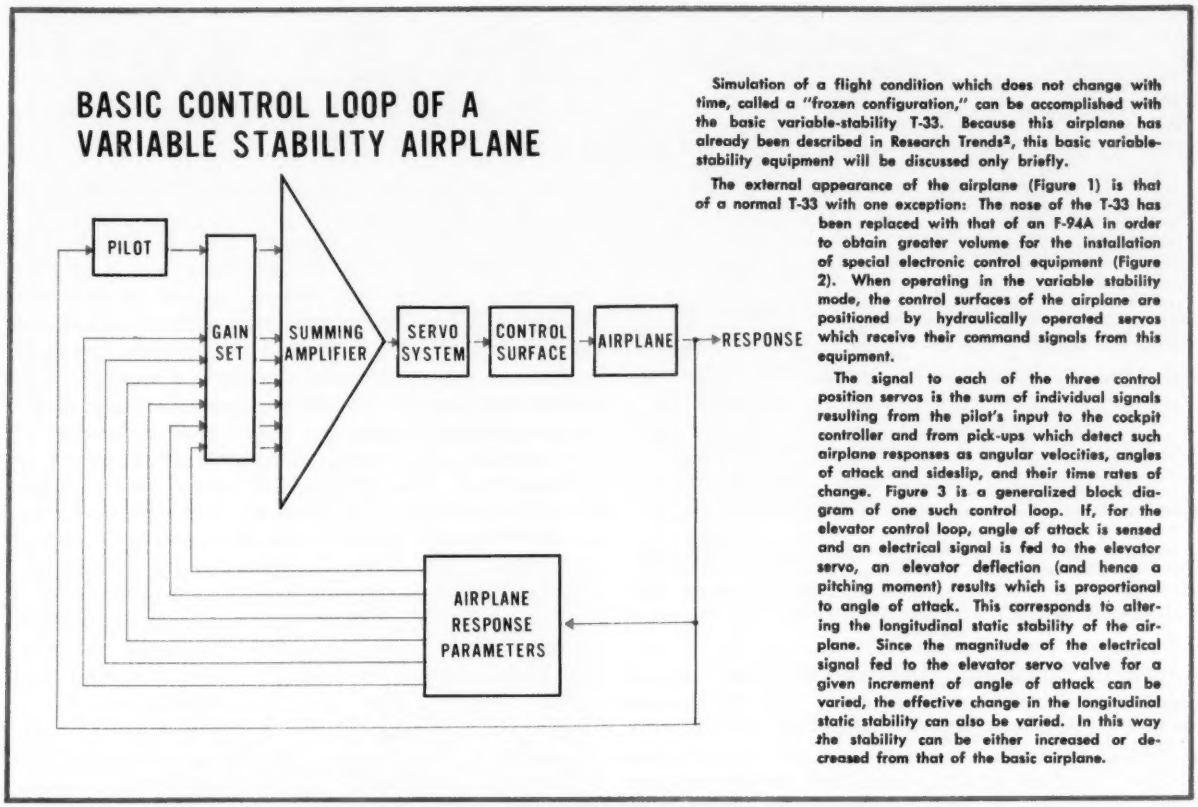
BASIC CONTROL LOOP OF A VARIABLE STABILITY AIRPLANE
PILOT
GAIN SET
SUMMING AMPLIFIER
SERVO SYSTEM
CONTROL SURFACE
AIRPLANE
RESPONSE
AIRPLANE RESPONSE PARAMETERS
Simulation of a flight condition which does not change with time, called a "frozen configuration," can be accomplished with the basic variable-stability T-33. Because this airplane has already been described in Research Trends[2], this basic variable-stability equipment will be discussed only briefly.
The external appearance of the airplane (Figure 1) is that of a normal T-33 with one exception: The nose of the T-33 has been replaced with that of an F-94A in order to obtain greater volume for the installation of special electronic control equipment (Figure 2). When operating in the variable stability mode, the control surfaces of the airplane are positioned by hydraulically operated servos which receive their command signals from this equipment.
The signal to each of the three control position servos is the sum of individual signals resulting from the pilot's input to the cockpit controller and from pick-ups which detect such airplane responses as angular velocities, angles of attack and sideslip, and their time rates of change. Figure 3 is a generalized block diagram of one such control loop. If, for the elevator control loop, angle of attack is sensed and an electrical signal is fed to the elevator servo, an elevator deflection (and hence a pitching moment) results which is proportional to angle of attack. This corresponds to altering the longitudinal static stability of the airplane. Since the magnitude of the electrical signal fed to the elevator servo valve for a given increment of angle of attack can be varied, the effective change in the longitudinal static stability can also be varied. In this way the stability can be either increased or decreased from that of the basic airplane.

FIG. 3 — **Block diagram of basic control loop of a variable stability airplane.**

acceleration, increase directly with dynamic pressure if angle of attack is maintained constant. Also associated with the increase in dynamic pressure is a decrease in the periods of the longitudinal and lateral oscillations and an increase in their damping. Damping is quite low, however, if stability augmentation is not provided. In addition, there is also an increase of control sensitivity and authority.

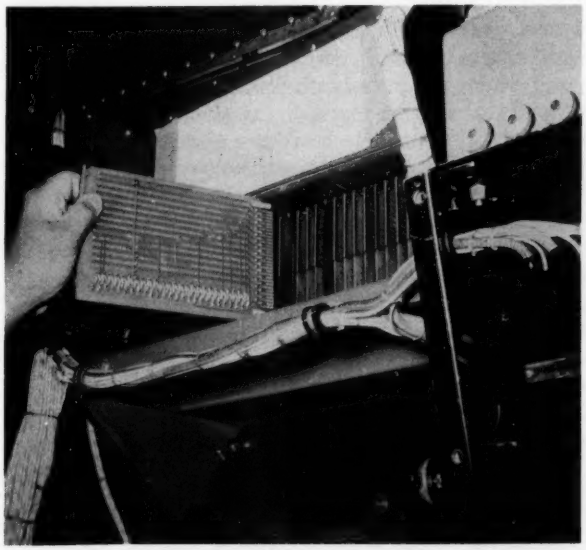

FIG. 4 — **The programmer with one of the 22 resistance boards being inserted. Remaining resistance boards can be seen installed in the compartment. Each board is mechanically keyed so that it can be installed only in the proper slot of the compartment.**

Re-entry must be made at a sufficiently high angle of attack so that the flight path is curved fast enough to prevent the airplane from reaching relatively dense air at very high speed and hence overheating. On the other hand, if the angle of attack is too high, excessive acceleration or deteriorated handling qualities will result. The pilot's task during re-entry, then, is to control the load factor accurately as the X-15 trajectory progresses from near-zero g to a multiple g pull-out. During the re-entry the pilot must adapt to a wide variation of stability and control characteristics.

The technique used by the pilot of the X-15 when making a re-entry is generally this: While still in the essentially ballistic trajectory, and before aerodynamic forces become significant, the pilot trims the X-15 to a predetermined angle of attack. This angle of attack is maintained as the dynamic pressure, lift, and normal acceleration increase. When the normal acceleration reaches a specified value, the pilot commences to reduce the angle of attack. Normal acceleration is maintained at the specified value until the rate of descent reduces to zero, at which time the normal acceleration is reduced and a one-g glide is established.

Simulating the Re-entry Maneuver

When simulating the X-15 re-entry with the T-33, the control-system gains for matching the stability and control characteristics of the X-15 change if the speed

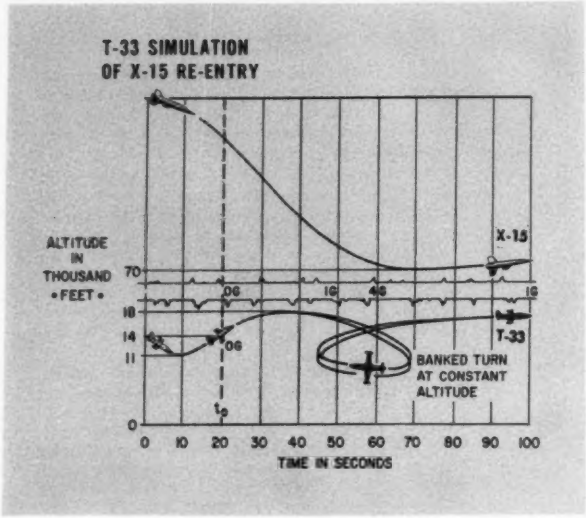

FIG. 5 — **Comparison of X-15 and T-33 re-entry trajectories. The T-33 does not reduce its altitude during the turn, nor does it, of course, go "backwards in time." Both discrepancies are a part of the illustrator's convention used to show that the airplane is circling.**

and altitude of the T-33 differ from the values assumed when these gains were determined. The gains can be set to allow the speed and altitude of the T-33 to vary, provided that the T-33 always conforms, within reasonable limits, to the same speed-altitude relationship. However, the task of setting the gains under these conditions would almost certainly be so complex as to be impracticable if these variations were large. For this reason the simulated maneuver must be flown with as little change of T-33 speed and altitude as possible. This can be done if that part of the re-entry maneuver requiring load factors in excess of one g is flown in a properly banked turn.

Pilot Executes Maneuver

The general relationship between the X-15 re-entry and its T-33 simulation is shown in Figure 5. The safety pilot puts the T-33 into a dive to a speed near the maximum permissible, and then pulls up to a 45° climb angle. At this point, the T-33 is pushed over to nearly zero g, and it arches upward in a nearly parabolic trajectory. The safety pilot then engages the special control system, "hands off" the airplane to the evaluation pilot in the front cockpit, and starts the programmer. Upon taking control of the airplane, the evaluation pilot rotates the T-33 until the angle of attack displayed agrees with the specified re-entry angle of attack of the X-15. If the maneuver is flown properly, the programmer is synchronized with the maneuver so that the evaluation pilot, by following the prescribed angle of attack and normal acceleration schedules for re-entry, will automatically keep the T-33 on the specified speed-altitude history which has been used to set the control system gain requirements.

As described above, the final part of the X-15 re-entry is a long pull-out maneuver. The best way to simulate an extended period at more than one g in the T-33 is to fly a banked turn. For reasons which will be mentioned below, the evaluation pilot controls the bank-angle of his wings by referring to his bank-angle indicator. The introduction of a bias signal into the bank-angle display causes the evaluation pilot to enter a turn at the proper load factor, or g, while thinking he is performing a wings-level pullout. The safety pilot increases thrust during the turn to maintain the required speed.

Re-entry of the X-15 occurs at high altitude, and is essentially an instrument flight task. The X-15 pilot maintains a wings-level attitude largely by reference to the roll bar of his attitude indicator. As stated above, during the early part of the re-entry, the X-15 pilot attempts to set and maintain a prescribed angle of attack, and the lift then increases because of increasing dynamic pressure. This automatic increase of lift without pilot input is achieved in the T-33 in this manner: The programmer calls for the proper incremental amount of elevator as a function of time, while the gain of the displayed angle of attack channel is reduced. The evaluation pilot's angle-of-attack indicator then shows no increase as normal acceleration increases. The T-33 must enter a turn as the normal acceleration increases, or it will commence to climb. In order to induce the evaluation pilot to enter a turn while thinking that he is maintaining wings-level flight, the roll reference bar of the attitude indicator is displaced by a signal from the programmer. The bank-angle commanded by the programmer is computed from the required time variation of load factor.

Pilot is Hooded

But one more element is required to make the deception realistic. Since the X-15 re-entry task is an instrument flight task, the evaluation pilot in the T-33 is hooded, and has no visual clues that he is banked. The rates of roll required to follow the commanded bank-angle are well within the capability of the X-15 at each point during the re-entry, and very little lateral control deflection is needed to follow the bias introduced to the attitude indicator. The evaluation pilot is not aware of the fact that he has banked the airplane. Neither is he especially aware that the attitude indicator calls for him to return the T-33 to actual wings-level flight as the rate-of-descent indication goes to zero near the end of the maneuver. The programmer has, of course, varied the stability and control characteristics of the airplane from loose and sluggish to tight and responsive as the maneuver progresses.

The flight technique described above using the variable stability T-33, has permitted the group of X-15 pilots to experience the "feel" of re-entry before actually accomplishing this hazardous maneuver.

REFERENCES

1. "Airplanes with Variable Stability", Breuhaus, W. O., Cornell Aeronautical Laboratory, Inc., RESEARCH TRENDS, Vol. III, No. 2, Summer 1955.

2. "Analog Computer with Wings", Beilman, J. L., Cornell Aeronautical Laboratory, Inc., RESEARCH TRENDS, Vol. V, No. 2, Summer 1957.

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COATED ABRASIVES RESEARCH . . .

by H. T. McADAMS

Against a background of advanced space projects, research dealing with coated abrasives appears anachronistic. Yet mathematical techniques, many derived from the challenging problems of Cornell Aeronautical Laboratory's space research, can be applied to improving coated abrasives. Certainly sandpaper, one of the many forms of coated abrasives, is a household word and has long been taken for granted. Although many important improvements in coated abrasives

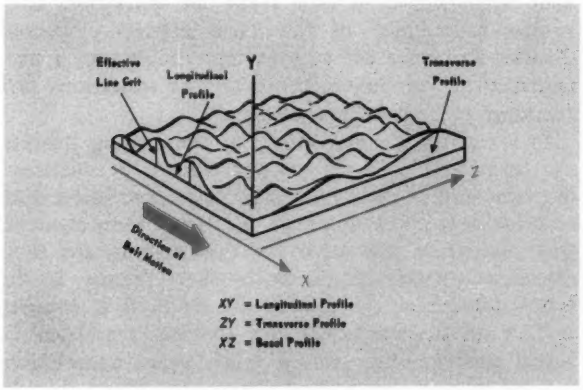

FIG. 1 — **Topography of an abrasive belt.**

have been made in recent years, a basic approach to design was still desirable. It was this desire that prompted the Carborundum Company of Niagara Falls to sponsor what has come to be known at the Laboratory as Project Grit. Under Project Grit a theoretical basis for improved design was sought.

Abrasive grits in a grinding belt act somewhat like tool bits in milling machines and lathes. Each abrasive particle removes minute chips from the workpiece, as if the particle were a miniature cutting tool. In contrast to the fixed geometry of single-point cutting tools, however, grits are seldom of uniform shape, and statistical methods have to be employed. In addition to the mechanical factors affecting design, chemical reactions play an important role in abrasive performance at the high temperatures often found at the cutting interface. Therefore, a comprehensive attack on the design problem demands the application of a number of disciplines, including mathematics, physics, chemistry and various branches of engineering.

Coated Abrasive Topography

Every do-it-yourself enthusiast is aware that various grades of sandpaper differ in roughness and in the surface finish produced on the workpiece. For design purposes, however, one must be able to measure accurately ***degrees*** of roughness and to relate these measurements to cutting efficiency. More specifically, one must be able to compute statistics characterizing the topography of the coated abrasive product and to correlate this data with cutting efficiency.

Figure 1 is a sketch of a section of a coated abrasive. This sketch might represent a piece of sandpaper of the household variety, a section of a large abrasive belt used for heavy snagging operations, a piece of sanding disc used in floor sanders, or any of some 30,000 to 40,000 special varieties of coated abrasive products. In all cases, important factors affecting the quality of the coated abrasive surface are the size, shape, orientation, and area distribution of the grit particles.

As shown in Figure 2, the passage of individual grit particles through the workpiece may be thought of as so many separate cutting events, each of which removes a chip from the workpiece. These cutting events are related in time in a definite way, the relation depending on topographic features of the coated abrasive and on the motion of the abrasive relative to the workpiece. Accordingly, for best performance, the topography of the coated abrasive should be suitably matched to the grinding task.

Grinding Kinematics and Chip Formation

For an accurate picture of the manner in which bits of stock are removed from the workpiece, appropriate mathematical expressions must be derived to describe the paths or trajectories of the cutting particles during their contact with the workpiece. Such an analysis makes it possible to assess the size of the chips produced and the loads to which the grit particles are subjected.

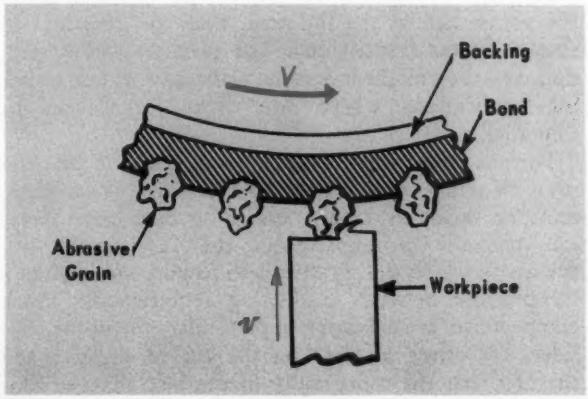

FIG. 2 — **The cutting process.**

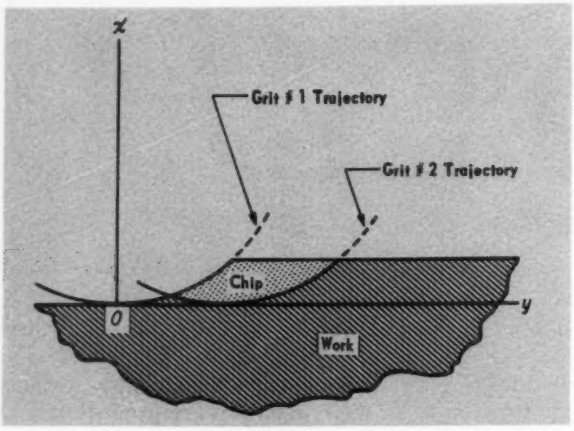

FIG. 3 — **Geometry of two-dimensional chips.**

Various grinding configurations are possible. In Figure 2, for example, the workpiece moves perpendicularly to the direction of motion of the cutting particles in a configuration often referred to as plunge grinding. In surface grinding, on the other hand, the workpiece moves in a straight line tangent to the abrasive belt which may be applied to the workpiece by a powered contact wheel. In the two cases the path taken by the cutting particle in its motion through the workpiece is considerably different.

Successive trajectories define the chips to be removed from the workpiece (Fig. 3). For efficient stock removal, the chips should be relatively large, but for fine surface finish the chips should be small.

Large chips are produced by increasing the depth of cut and by allowing relatively large distances between the grit particles on the abrasive belt. Under such conditions, however, high loads are imposed on the grit particles. If these loads are excessive, the abrasive grains may break or may be dislodged from the adhesive which binds them to the backing sheet. In some cases, they may even be forced through the paper or cloth backing.

Belt Designed for Ruggedness

For heavy grinding tasks, therefore, all components of the abrasive belt — grit particles, bond, and backing — must be designed with ruggedness as a primary consideration. Grit particles capable of withstanding high loads must have relatively large cross sections, or, in the vernacular of the industry, must be "blocky" in shape. To the layman, such grit particles would seem dull, and they might indeed be ineffective in fine grinding applications where only light forces can be tolerated.

For the latter type of application, the grit particles must be sharp, and, because of their limited strength, must be relatively closely spaced so that large forces are avoided. Optimum design, therefore, varies with the use to which the abrasive is to be put, and is often a compromise between conflicting requirements. Such compromises are necessary in particular, when one considers the effect of wear on the coated abrasive and the fact that the topography of the belt changes continuously as a result of such wear.

In many applications, the most important property of a coated abrasive is its total production potential — that is, the total amount of stock it can remove before having to be replaced. Cutting particles become dulled with increased use and ultimately reach a non-usable condition. To obtain a clearer understanding of the wear process and its effect on cutting rate, it is necessary to develop a model of the cutting process and to visualize how the process is affected by the wear of grit particles.

Mechanics of Cutting

The classical approach to the mechanical analysis of grinding has been by way of analogy to the cutting action of single-point cutting tools. In grinding, as in other cutting operations, the work material is cut into many pieces, a new piece being produced each time a chip is separated from the workpiece. From the point of view of engineering mechanics which considers the magnitude and direction of the forces acting on a body, each separation of a chip from the workpiece constitutes a "failure" of the work material. Various theories of failure are current; applicability of a particular theory usually depends on the conditions surrounding the particular failure.

In a widely accepted model of the cutting process, the formation of a chip is represented as successive displacements of plate-like elements stacked like a deck of cards, as shown in Figure 4. Sliding of these elements with respect to each other constitutes shear, and their interfaces are referred to as the shear planes. In the simplest form of the model, the material is assumed to flow off the workpiece in a continuous ribbon. In actual practice, however, a much more complicated process, giving rise to a discontinuous chip, may be involved. In addition, minute particles of the work material may become welded to the tool point and may subsequently be dislodged, so that the geometry of the cutting tool fluctuates in an erratic manner.

In Figure 5 a planing operation is envisioned and the applicable force diagram is shown. The chip is regarded as being held in equilibrium between two equal and opposite forces R and R^1. The force R on the shear plane can be resolved into components parallel and perpendicular to the shear plane. A chip is removed when the forces are such that the shear stress on the shear plane exceeds the shear strength of the material being cut.

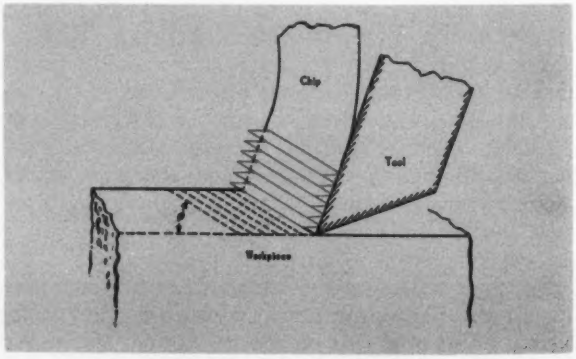

FIG. 4 — **Stacked-card model of chip formation.**

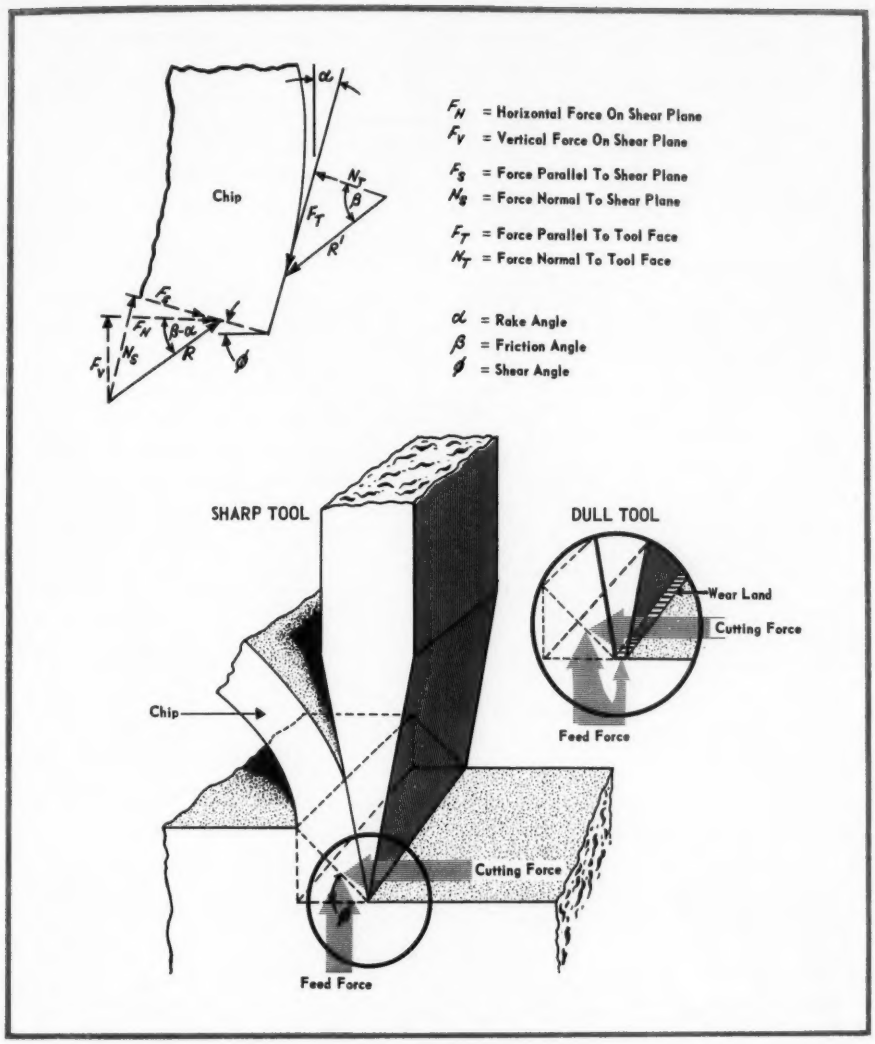

FIG. 5 — **Orthogonal cutting.**

Of particular interest in the resolution of the applied force R into components F_H and F_V acting respectively horizontally and vertically on the shear plane. The vertical component is the feed force; the horizontal component the cutting force.

Effect of Wear

As the grit particle wears, a flat surface or wear land may develop at its point, as shown in Figure 5. As a result, the feed force is shared between the shear plane and the plane of contract between the wear land and the new work surface. An additional frictional force is introduced as a rubbing force on the wear land. The net result is that the grit particle, for a given applied feed force, will not penetrate as deeply into the workpiece as it did before the wear land developed. To maintain the same rate of stock removal, therefore, it is necessary to increase the feed force to compensate for the development of the wear land on the cutting particle.

Eventually, forces on the grits may become so great that some of the particles are dislodged. As a result of the weakened sites thus produced, the coated abrasive begins to break down rapidly and very shortly must be discarded. It is evident that by proper control of particle shape and orientation, this wear and breakdown process is subject to control. Ideally, conditions should be such that when particles become dull or loaded with debris they automatically fracture to produce new sharp cutting edges.

For a number of reasons, grinding is perhaps the least understood of all cutting processes. Grit particles, unlike most cutting tools, have a highly variable geometry; two particles seldom, if ever, have the same size, shape, or orientation with respect to the workpiece. Cutting speeds are often much higher than in other cutting operations and the depth of cut taken by an abrasive grain may be only a few microinches, much smaller than in the case of other cutting tools.

At the cutting speeds involved, allowance must be made for the fact that the mechanical properties of both grit and workpiece may be considerably different from those measured under essentially static conditions. For example, it is evident that at grinding speeds of say, 10,000 surface feet per minute, very high rates of strain are prevalent and that at these high strain rates the mode of failure of the work material may be appreciably altered.

The implication of these phenomena for coated abrasive design are being studied, and attempts are being made to obtain a better physical picture of the grinding process.

In summary, a major part of the research effort under Project Grit has been the interpretation and application of metal cutting theory to the unique conditions prevailing in the grinding process. Grit geometry, grit spacing, depth of cut, grinding speed, grinding forces, wear and other parameters are interrelated in a complex manner. A mathematical model providing a conceptual framework for properly interrelating these parameters and for studying their effect on grinding performance has been formulated. The result is expected to be coated abrasive products of improved cutting efficiency.

RECENT CAL PUBLICATIONS

The Laboratory invites requests for its unclassified publications as a public service. Supplies of some publications are limited. Please direct your request to the Editor, Research Trends, Cornell Aeronautical Laboratory, Buffalo 21, New York.

"AERO AND HYDRO-ELASTICITY," Flax, A. H.; Paper presented before First Symposium on Naval Structural Mechanics, Stanford University, August 11-14, 1958; 48 pages.

Aeroelasticity is concerned with the mutual interaction between the aerodynamic forces acting upon a vehicle moving through the air and its structural deformation. Insofar as the fundamentals of the subject are concerned it matters not whether the vehicle is moving in air or water, provided that the effects of the free surface of the water may be neglected.

"THE ABILITY OF SUBMERGED SUBJECTS TO SENSE THE GRAVITATIONAL VERTICAL," Diefenbach, W. S.; CAL Report No. OM-1355-V-1; January 1961; 39 pages.

The ability of human subjects to perceive the vertical when submerged in a buoying fluid and subjected to varying amounts of body tilt was studied in a series of pilot experiments. Experimental equipment employed attempted to minimize positional cues other than those arising from the vestibular apparatus and visceral sources. Gross errors in perception of the vertical were made by all subjects. These errors were repeatable within subjects, and had a high linear correlation with the amount of body tilt. In addition, evidence was found that precision in positioning an unseen control may vary with body tilt. Possible simulation of weightlessness and implications for design of space controls are briefly discussed and further research studies are suggested.

"PROPAGATION OF WEAK DISTURBANCES IN A GAS SUBJECT TO RELAXATION EFFECTS," Moore, Franklin K., Gibson, Walter E.; Reprinted from the Journal of Aero/Space Sciences, Vol. 27, No. 2, February 1960; 10 pages.

A generalized wave equation is derived for sound disturbances in a gas when relaxation effects connected with, for example, molecular vibration or dissociation are important. Solutions involving discontinuous wave fronts are presented, and it is shown that, under certain assumptions, the complete wave equation reduces to a variant of the telegraph equation. Detailed solutions are presented for disturbance fields produced by a wavy wall in subsonic and supersonic flow and a simple wedge in supersonic flow.

"CONTROL SYSTEM PERFORMANCE MEASURES: PAST, PRESENT AND FUTURE," Schultz, W. C., Rideout, V. C.; Reprinted from I.R.E. Transactions on Automatic Control, Vol. AC-6, No. 1; February 1961; 12 pages.

An increased amount of emphasis on the mathematical formulation of control system performance can be found in recent literature on automatic control. There are two areas of control system theory in which the application of performance measures is of interest; 1) the evaluation of control system designs in general, and 2) the design of adaptive control systems.

"FREEZING RAIN EXPERIMENTS-PROJECT FREEZE," Meese, Harold F.; CAL Report No. VC-1135-P-1; March 1961; 10 pages.

The basic objective of Project FREEZE has been to determine experimentally whether or not freezing rain can be converted to solid precipitation before it reaches the ground. Experiments were designed to produce, for a ground-based generator, a cloud of freezing nuclei (silver iodide was used) to intercept the super cooled raindrops and cause them to solidify before reaching the ground. The results of these experiments, described in Reference 1, were encouraging but not conclusive.

"CHEMICAL NONEQUILIBRIUM EFFECTS ON HYDROGEN ROCKET IMPULSE AT LOW PRESSURES," Hall, J. Gordon, Eschenroeder, Alan Q., Klein, James J.; Reprinted from A.R.S. Journal, Vol. 30, No. 2; February 1960; 2 pages.

The purpose of the present note is to report calculations of nonequilibrium hydrogen flows for a lower range of pressures as well as a wider range of temperatures and nozzle geometry than previously considered.

ABOUT THE AUTHORS

WALDEMAR O. BREUHAUS, author of "Dry Run in the X-15" is head of Cornell Aeronautical Laboratory's Flight Research Department, and responsible for guiding and directing the department's research in airplane stability and control, flight testing, and studies of flight-control characteristics.

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Before joining Cornell Aeronautical Laboratory in 1946, Mr. Breuhaus spent six years with the Chance Vought Aircraft Division of the United Aircraft Corporation. He was named head of the Flight Research Department at CAL in 1956 after serving as section head and assistant department head.

Mr. Breuhaus is a member of the Institute of Aerospace Sciences, Tau Beta Pi, the New York State Society of Professional Engineers and Sigma Xi.

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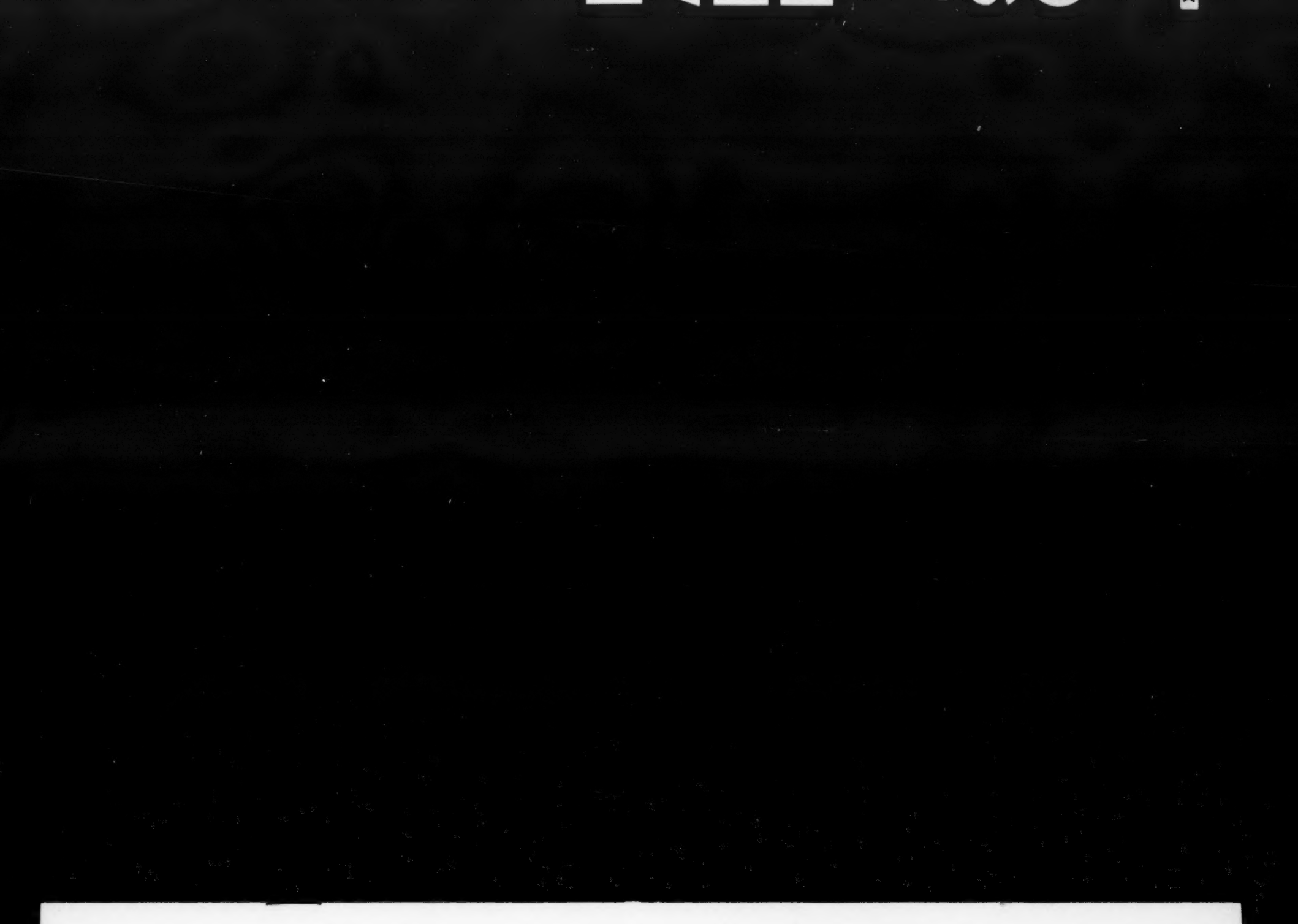
Mr. McAdams received a B.E. degree in Mathematics from the Illinois State Normal University and a master of arts degree from the University of Buffalo. Before joining the staff of CAL in 1953, he worked as a research physicist for the Western Cartridge Company, as an extension instructor for the University of Illinois, and as a research chemist for the Aluminum Research Laboratories.